A WELLBORE APPARATUS AND METHOD FOR COMPLETION, PRODUCTION AND INJECTION

FIELD OF THE INVENTION

This invention relates generally to an apparatus and method for use in wellbores. More particularly, this invention relates to a wellbore production completion maze apparatus and method suitable for fluid production and gravel packing.

BACKGROUND

Hydrocarbon production from subterranean formations commonly includes a wellbore completed in either cased hole or open hole condition. In cased-hole applications, a wellbore casing is placed in the wellbore and the annulus between the casing and the wellbore is filled with cement. Perforations are made through the casing and the cement into the production zones to allow formation fluids (such as, hydrocarbons) to flow from the production zones into the casing. A production string is then placed inside the casing, creating an annulus between the casing and the production string. Formation fluids flow into the annulus and then into the production string to the surface through tubing associated with the production string. In open-hole applications, the production string is directly placed inside the wellbore without casing or cement. Formation fluids flow into the annulus between the formation and the production string and then into production string to surface.

When producing fluids from subterranean formations, especially poorly consolidated formations or formations weakened by increasing downhole stress due to wellbore excavation and fluids withdrawal, it is possible to produce solid material (for example, sand) along with the formation fluids. This solids production may reduce well productivity, damage subsurface equipment, and add handling cost on the surface. Several downhole solid, particularly sand, control methods being practiced in

industry are shown in Figures 1(a), 1(b), 1(c) and 1(d). In Figure 1(a), the production string or pipe (not shown) typically includes a sand screen or sand control device **1** around its outer periphery, which is placed adjacent to each production zone. The sand screen prevents the flow of sand from the production zone **2** into the production string (not shown) inside the sand screen **1**. Slotted or perforated liners can also be utilized as sand screens or sand control devices. Figure 1(a) is an example of a screen-only completion with no gravel pack present.

One of the most commonly used techniques for controlling sand production is gravel packing in which sand or other particulate matter is deposited around the production string or well screen to create a downhole filter. Figures 1(b) and 1(c) are examples of cased-hole and open-hole gravel packs, respectively. Figure 1(b) illustrates the gravel pack **3** outside the screen **1**, the wellbore casing **5** surrounding the gravel pack **3**, and cement **8** around the wellbore casing **5**. Typically, perforations **7** are shot through the wellbore casing **5** and cement **8** into the production zone **2** of the subterranean formations around the wellbore. Figure 1(c) illustrates an open-hole gravel pack wherein the wellbore has no casing and the gravel pack material **3** is deposited around the wellbore sand screen **1**.

A variation of a gravel pack involves pumping the gravel slurry at pressures high enough so as to exceed the formation fracture pressure (frac pack). Figure 1(d) is an example of a Frac-Pack. The well screen **1** is surrounded by a gravel pack **3**, which is contained by a wellbore casing **5** and cement **8**. Perforations **6** in the wellbore casing allow gravel to be distributed outside the wellbore to the desired interval. The number and placement of perforations are chosen to facilitate effective distribution of the gravel packing outside the wellbore casing to the interval that is being treated with the gravel-slurry.

Flow impairment during production from subterranean formations can result in a reduction in well productivity or complete cessation of well production. This loss of functionality may occur for a number of reasons, including but not limited to, migration of fines, shales, or formation sands, inflow or coning of unwanted fluids (such as, water or gas, formation of inorganic or organic scales, creation of emulsions

or sludges), accumulation of drilling debris (such as, mud additives and filter cake), mechanical damage in sand control screen, incomplete gravel pack, and mechanical failure due to borehole collapse, reservoir compaction/subsidence, or other geomechanical movements.

U.S. Patent 6,622,794 discloses a screen equipped with flow control device comprising helical channels. The fluid flow through screen could be reduced via helical paths, fully opened, or completely closed by controlling downhole apertures from the surface. U.S. Patent 6,619,397 discloses a tool for zone isolation and flow control in horizontal wells. The tool is composed of blank base pipes, screens with closeable ports on the base pipe, and conventional screens positioned in an alternating manner. The closeable ports allow complete gravel pack over the blank base pipe section, flow shutoff for zone isolation, and selective flow control. U.S. Patent 5,896,928 discloses a flow control device placed downhole with or without a screen. The device has a labyrinth which provides a tortuous flow path or helical restriction. The level of restriction in each labyrinth is controlled by a sliding sleeve so that flow from each perforated zone (for example, water zone, oil zone) can be adjusted. U.S. Patent 5,642,781 discloses a wellbore screen jacket composed of overlapped helical-shaped members wherein the openings allow fluid flow through alternate contraction, expansion and provide fluid flow direction change in the wellbore (or multi-passage). Such design may mitigate solids plugging of screen jacket openings by establishing both filtering and fluid flow momentum advantages.

Current industry well designs include little, if any, redundancy in the event of problems or failures resulting in flow impairment. In many instances, the ability of a well to produce at or near its design capacity is sustained by only a "single" barrier to the impairment mechanism (for example, screen for ensuring sand control in unconsolidated formations). In many instances the utility of the well may be compromised by impairment occurring in a single barrier. Therefore, overall system reliability is very low. Flow impairment in wells frequently leads to expensive replacement drilling or workover operations.

The current industry standard practice utilizes some type of sand screen either alone or in conjunction with artificially placed gravel packs (sand or proppant) to retain formation sand. All of the prior art completion types are "single barrier" completions, with the sand screen being the last "line of defense" in preventing sand from migrating from the wellbore into the production tubing. Any damage to the installed gravel pack or screen will result in failure of the sand control completion and subsequent production of formation sand. Likewise, plugging of any portion of the sand control completion (caused by fines migration, scale formation, etc.) will result in partial or complete loss of well productivity.

Lack of any redundancy in the event of mechanical damage or production impairment results in the loss of well productivity from single barrier completion designs. Accordingly, there is a need for a well completion apparatus and method to provide multiple flow pathways inside the wellbore that provides redundant flow pathways in the event of mechanical damage or production impairment.

SUMMARY

A wellbore apparatus is disclosed. The apparatus comprises a first flow joint in a wellbore, the first flow joint comprising at least one three-dimensional surface defining a first fluid flow path through the wellbore with at least one section of the first flow joint surface being permeable and at least one section of the first flow joint surface being impermeable. A second flow joint in a wellbore, the second flow joint comprising at least one three-dimensional surface defining a second fluid flow path through the wellbore with at least one section of the second flow joint surface being permeable and at least one section of the second flow joint surface being impermeable. At least one permeable section of the first flow joint is connected to at least one permeable section of the second flow joint thereby providing at least one fluid flow path between the first flow joint and the second flow joint. In one embodiment, at least one flow joint comprises a shunt tube to provide a flow path to the annulus for gravel packing.

A method of well completion, production and injection is also disclosed. The method comprises providing a wellbore completion apparatus for gravel packing and for producing hydrocarbons in a wellbore. The wellbore completion apparatus comprising a first and second flow joint in a wellbore. The first flow joint comprising at least one three-dimensional surface defining a first fluid flow path through the wellbore with at least one section of the first flow joint surface being permeable and at least one section of the first flow joint surface being impermeable. The second flow joint comprising at least one three-dimensional surface defining a second fluid flow path through the wellbore with at least one section of the second flow joint surface being permeable and at least one section of the second flow joint surface being impermeable. At least one permeable section of the first flow joint is connected to at least one permeable section of the second flow joint thereby providing at least one fluid flow path between the first flow joint and the second flow joint. The production apparatus is installed into the wellbore to thereby providing multiple flowpaths in the wellbore. Hydrocarbons can then be produced from the well using the installed production apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1(a) is an illustration of a bare screen sand control completion;

Figure 1(b) is an illustration of a cased-hole gravel pack sand control completion;

Figure 1(c) is an illustration of an open-hole gravel pack sand control completion;

Figure 1(d) is an illustration of a frac-pack sand control completion;

Figure 2(a) is an illustration of fluid production from a subterranean formation using an embodiment of the Mazeflo completion system;

Figure 2(b) is a cross-section illustration of fluid production from a subterranean formation using the Mazeflo completion system of figure 2(a);

Figure 3(a) is a cross-section illustration of a possible flow joint configuration using permeable or partially permeable surfaces;

Figure 3(b) is a cross-section illustration of a flow joint configuration using permeable or partially permeable surfaces attached to a concentric tube inside a wellbore;

Figure 3(c) is a cross-section illustration of a flow joint configuration using a permeable or partially permeable surface with multiple eccentric tubes inside the wellbore;

Figure 3(d) is a side-view illustration of the flow joint configuration of figure 3(a) using a permeable or partially permeable surfaces;

Figure 4(a) is a longitudinal view of concentric multiple flow joints in a wellbore;

Figures 4(b), 4(c) and 4(d) are cross-sectional views of figure 4(a) at designated locations of the wellbore;

Figure 5(a) is the longitudinal view of concentric multiple flow joints further illustrating possible placements for shunt tubes and nozzle ports;

Figures 5(b), 5(c) and 5(d) with are cross-sectional views of figure 5(a) at designated locations of the wellbore;

Figure 6(a) is a side view of a wellbore using an embodiment of the Mazeflo completion system illustrating a possible fluid flowpath during sand infiltration into a wellbore;

Figure 6(b) is a end view of a wellbore using an embodiment of the Mazeflo completion system illustrating a possible fluid flowpath during sand infiltration into the wellbore.

DETAILED DESCRIPTION

In the following detailed description, the invention will be described in connection with its preferred embodiments. However, to the extent that the following

description is specific to a particular embodiment or a particular use of the invention, this is intended to be illustrative only. Accordingly, the invention is not limited to the specific embodiments described below, but rather, the invention includes all alternatives, modifications, and equivalents falling within the true scope of the appended claims.

This invention describes an apparatus that embodies a well completion design providing significant flowpath redundancies to address wellbore mechanical damage and flow impairment problems in wells. The invention is referred to as a "Mazeflo completion" system or the wellbore completion apparatus or system since it utilizes the concept of a maze in the design of a completion. The maze design permits greater flexibility, selectivity, and self-adjusting control in the event of mechanical damage or production flow impairment problems in wells.

This invention is referred to as a Mazeflo completion system or apparatus because the apparatus involves installation (completion) in a wellbore. The claimed apparatus may be used for completing, gravel packing, flow control, providing hydrocarbon and fluid injecting. Persons skilled in the art with the benefit of the disclosure herein will recognize multiple applications for the apparatus. All such applications and methods for using the apparatus are intended to be within the scope of the claims.

The Mazeflo completion system in the wellbore allows the isolation of flow impairing materials while still permitting the movement of fluids through other available pathways in the well. The Mazeflo completion system comprises flow joints or three-dimensional surface (such as, a cylindrical surface) defining a fluid flow path or hollow body capable of transporting fluids such as, tubular or channel-section piping with various permeable and impermeable surfaces. The use of various combinations of permeable and impermeable surfaces, walls and baffles or flow diverters permits the construction of multiple compartmentalized fluid flow paths. The compartmentalized fluid flow paths ensure the continuous production of fluids from within and around the well.

The use of baffles may include walls to completely or partially divide the compartments to redirect the fluid flow paths or change the fluid flow velocity. Baffles can be used as the permeable or impermeable surfaces of the flow joints. Permeable surfaces may be constructed from a variety of materials and devices. Permeable surface devices include but are not limited to: wire-wrapped screens, membrane screens, expandable screens, sintered metal screens, wire-mesh screens, slotted liners, perforated liners, or pre-packed solid particle beds.

A Mazeflo completion system can be constructed using numerous combinations of flow joints creating distinct flow path including sections of both separate and commingled fluid flow pathways. Examples of creating flow joints include placing or attaching permeable or impermeable materials juxtapositionally, either concentrically or adjacent to each other. The compartments may be positioned longitudinally or transverse to one another, or possibly bundled and manifolded at some locations. The Mazeflo completion system may also be accommodated by or protected by an outer shroud. Depending upon the amount of flow impairment and the specific design, the compartments can serve as redundant fluid flow paths (such as, primary, secondary, tertiary, etc. flow paths).

Figure 2(a) illustrates fluid production from a wellbore **10** in a subterranean formation using an embodiment of the Mazeflo completion system. In this embodiment of the Mazeflo completion system, a number of first or primary **13** and second or secondary **15** longitudinal cylindrical permeable joints of pipe are used. Impermeable joints **29** or flexible joints may be used to connect the joints of pipe.

The term primary is used to designate the joints through which the operator believes the largest amount of fluid flow will initially occur. Secondary flow joints and tertiary or second and third or higher flow joints respectively are alternate fluid flow paths that are typically (but not always) smaller in size. In fact, the majority of flow may occur in the second or if available third or higher numbered flow joints. Thus, the determination of primary and secondary flow joints is purely illustrative. Labeling of flow joints as primary, secondary, and tertiary flow joints can facilitate understanding the invention as there will most likely be a preferred first flow path (or

primary flow joint), a second flow path (or secondary flow joint) and possibly a third flow path (tertiary flow joint). Therefore, the designation of primary, secondary, and tertiary flow joints is arbitrary and is not meant to limit the scope of the invention. Alternatively, as discussed above, the flow joints may be labeled, first, second, third and higher, if necessary, rather than primary, secondary and tertiary flow joints and vice versa. The fluid flow may be production fluids (fluids removal out of the well or injection fluids (fluids that are injected into the well).

In the embodiment illustrated in Figure 2 (a), a production string **11** is placed inside a wellbore **10**. Outside of the production string are at least two flow joints or three-dimensional cylindrical surfaces defining a hollow body capable of fluid flow. In Figure 2(a), at least one set of joints is a first (or primary) flow joint **13**. The first flow joint **13** comprises at least one three-dimensional cylindrical surface defining a hollow body capable of fluid flow with a portion of the first flow joint surface being permeable (shaded) and a portion of the joint being impermeable (not shaded). At least one flow joint is a second (or secondary) flow joint **15**. The second flow joint **15** comprises at least one three-dimensional cylindrical surface defining a hollow body capable of fluid flow with a portion of the surface being permeable (shaded) and a portion of the surface being impermeable (not shown). The length of the permeable and impermeable sections can be varied to obtain favorable fluid flow based on fluid flow dynamics and wellbore conditions. Preferably the length of the permeable and impermeable sections will be at least 7.5 centimeters (3 inches) long and more preferably at least 15 centimeters (6 inches) long.

At least one permeable section of the first flow joint **13** is connected to at least one permeable section of the second flow joint **15** thereby providing at least one fluid flow path between the first flow joint and the second flow joint. In the example of Figure 2(a), the connection of the first **13** and second flow paths **15** is through the annulus **25** of the wellbore **10** which permits fluid flow through the permeable walls of the first flow joint **13** to the permeable walls of the second flow joints **15**. The annulus **25** of the wellbore **10** can also be utilized as a third or tertiary flow joint. Other possible means for connecting a permeable section of the first flow path **13** to a

permeable section of a second flow path **15** include, having the first **13** and second flow path **15** share the same permeable surface or having tubing connect the permeable sections. Persons skilled in the art, based on the disclosure herein, will recognize other means for connecting a permeable surface of the first flow joint **13** to a permeable section of the second flow joint **15**. All such methods of connecting two permeable sections are included in this invention.

Arrow **19** indicates the direction of the hydrocarbon flow and arrows **17** illustrate possible flow paths through the primary **13** and secondary **15** flow joints. In this illustration the secondary flow joints **15** are connected to the primary flow joints **13** by mechanical connectors **21**. Persons skilled in the art will recognize other methods to securely position the primary **13** and secondary joints **15** in the wellbore **10**. As is illustrated by the fluid flow arrows **17**, the arrangement of primary flow joints **13** and secondary flow joints **15** provides at least two flow paths with at least one connection capable of fluid flow between the two flow paths through the production apparatus. This embodiment permits adding additional flow joints as necessary through the use of an annulus **25**, casing, well screen or other flow joint.

Figure 2(b) is a cross-sectional view illustrating the fluid flow from primary flow joints **13** to secondary flow joints **15** to the annulus **25** wherein like elements from Figure 2(a) are given the same reference numbers. The annulus **25** is the space between the primary **13** and secondary **15** flow joints and the casing (not shown) or formation sand **27** in an uncased well as in Figure 2(b). In this example, the annulus **25** is utilized as a third (or tertiary) flow joint as well as a connection between the permeable walls of the first **13** and second flow joints **15**. Furthermore, in this example, the production string **11** is a continuous tube inside the primary flow joint **13**. However, the production string **11** can be a continuous tube in a flow joint such as, the primary flow joint **13** of Figure 2(a) or it can be the inside of a flow joint and be continuous or discontinuous. As illustrated in Figure 2(a) the primary flow joints **13** are connected with the production string **11** serving as a connector **29**. The flow joints can be a discontinuous tube with connectors **29** as shown in Figure 2(a) or it can be a continuous three-dimensional surface capable of fluid flow.

There are five possible example flow scenarios for the embodiment shown in Figures 2(a) and 2(b). The first flow scenario is normal fluid flow through the primary joints **13**, secondary joints **15** and the annulus **25**.

The second possible fluid flow scenario occurs when the primary joint **13** is plugged and fluid will flow through the secondary flow joint **15** and the annulus **25** but not through the primary flow joint **13**. However, beyond the region where the primary flow joint **13** is plugged, the fluid flow would resume normal flow through the primary **13** and secondary flow joints **15** as well as the annulus **25**. Likewise, this scenario can occur when the secondary flow joint **15** or annulus **25** is plugged. The flow is then diverted to the unplugged flow joints.

The third fluid flow scenario occurs when a primary flow joint **13** and the annulus **25** around the primary flow joint are plugged. The fluid at that point will flow through the secondary joints **15** past the plugged region and then back into the annulus **25** and primary fluid flow joint, resuming normal flow.

The fourth flow scenario is when the primary **13** and secondary flow joints **15** are plugged. In this scenario fluid would flow through the annulus **25** past the plugged region of the primary **13** and secondary flow joints **15** and resume a normal flow path through the primary **13**, secondary flow joints **15** as well as through the well annulus **25**.

The fifth scenario occurs when the secondary joint **15** and the annulus **25** are plugged. In this scenario the fluid flows through the primary flow joint **13** past the plugged region of the secondary flow joint **15** and the annulus **25** and then resumes normal flow through the primary flow joint **13**, secondary flow joint **15** and the annulus **25**.

The specific combination of compartment baffles encompassing the Mazeflo completion system is determined based on the desired reliability, productivity, production profile, accessibility, and other functional requirements for the well. The design of the compartments and baffles is dependent on factors such as manufacturing, materials, locale of installation (for example, factory or via well

workover), and other desired functional requirements for the well. These other functional requirements may include, but are not limited to: exclusion of produced solids (sand control), improved mechanical strength or flexibility, exclusion or inclusion of specific fluids (downhole diversion and fluid conformance), delivery of treatment chemicals (for example, scale inhibitors, corrosion inhibitors, etc.), isolation of specific formation types, control of production rate and/or pressures, and measurement of fluid properties. Persons skilled in the art, with the benefit of the disclosures herein, can design the flow paths including the compartments and baffles for favorable fluid flow based on the functional requirements discussed above. The Mazeflo completion system may be used in cased-hole and open-hole wellbores, either for producers or injectors.

Figure 3(a) illustrates one embodiment wherein the flow joints are created by installing permeable or partially permeable surfaces **31** in the wellbore **10**. A portion of the surface **31** in the wellbore **10** is permeable and a portion is impermeable. The permeable surfaces allow commingling of the fluid flow from the different compartments as shown by fluid flow arrows **33**. The portions of the walls that are impermeable or partially permeable are equivalent to previously defined flow joints and allow fluid flow past the point where the other compartments are plugged.

Figure 3(d) is a side view illustration of Figure 3(a) to illustrate the walls inside the wellbore. The walls **31** in Figures 3(a) and 3(d) may be permeable, impermeable or contain some sections that are permeable and some sections that are impermeable.

An alternate embodiment is shown in Figure 3(b) where a first circular compartment **39** is inside a wellbore **10** and the space between the inner circular compartment **39** and the outer circular compartment (not shown) or wellbore **10** may be further compartmentalized by placing additional surfaces **31** between the inner circular compartment **39** and the wellbore **10**. In this embodiment the larger area outside circular compartment **39** would be designated the first flow joint **34**. Other outer circular compartments and the smaller inner compartment would be designated as second **36**, third **38**, and fourth **40** flow joints as shown in Figure 3(b). Additional

compartments (not shown) may be created and labeled fifth, sixth, and higher flow joints.

Figure 3(c) illustrates a different configuration embodiment wherein the two circular compartments **35** are inserted into a wellbore **10** and the wellbore **10** is further compartmentalized by the addition of a wall **31**. As discussed above, the walls would preferably have regions that are permeable and impermeable to provide commingling flow in some areas and separate distinct flows in other areas, allowing fluid flows to bypass regions where flow joints are plugged. The embodiment shown in Figure 3(c) would have five flow joints and the flow joints are labeled first **34**, second **36**, third **38**, fourth **40**, and fifth **44** as shown in Figure 3(c).

Figure 4(a) illustrates an additional embodiment of the Mazeflo completion system involving concentrically and longitudinally stacked multiple flow joints. As shown in Figure 4(a), each joint is bounded by either permeable (dashed line) **55** or impermeable (solid line) **57** media.

In this example, each stack of longitudinal compartments can be treated as a flow joint. Two examples of compartments are labeled **51** and **53** in Figure 4(a). In this example, the primary compartment or first flow joint **54** is the largest concentric compartment in the middle of the wellbore. The outermost compartment **51** and the compartment **53** between the outermost compartment and the innermost compartment are identified as the second and third flow joints or secondary, or tertiary flow joints respectively. If the outermost flow joint fails and particulates plug the flow joint, the outer wall of compartment **53** would prevent sand infiltration but allow fluid to pass through. Continuous sand invasion increases the sand concentration in the first flow joint **51** and subsequently increases the frictional pressure loss, resulting in gradually diminished fluid/sand flow into the first flow joint **51**. Fluid production is then diverted to other flow joints without permeable media failure.

Figures 4(b), 4(c), and 4(d) are cross-sectional views of Figure 4(a) at designated location of Figure 4(a) wherein like elements from Figure 4(a) are given the same reference numbers. These figures illustrate the changes from permeable

walls (dashed lines) to impermeable walls (solid lines) based on the location in the wellbore.

The permeable media **55** in Figure 4(a) could be a wire-wrapped screen wherein the gap between two wires is sufficient to retain most formation sand produced into wellbore. In one embodiment, the impermeable section **57** adjacent to the permeable media **55** could be formed by a blank pipe, impermeable material wrapped on the outside of a permeable media, or a wire-wrapped screen without a gap between adjacent wires. Manufacturing of a wire-wrapped screen is well known in the art and involves wrapping the wire at a present pitch level to achieve a certain gap between two adjacent wires. One embodiment of a Mazeflo screen could be manufactured by varying the pitch used to manufacture conventional wire-wrapped screens. For example, one portion of a single joint of wire-wrapped screen could be wrapped at a desired pitch that would retain most formation sand, as illustrated by **55** in Figure 4(a). The next portion of the screen could be wrapped at near zero or zero pitch (no gap) to be created an essentially impermeable media section as illustrated by **57** in Figure 4(a). Other portions of the screen joint could be wrapped at varying pitches to create varying levels of permeable sections or impermeable sections.

Additional compartments **50** inside the flow joint can be created by adding more walls **59**. The compartments **50** created by the additional walls **59** can be used as separate flow joints increasing the number of flow joints, thus increasing the number of redundancies. The wall **59** may be made of permeable material, impermeable material or with some sections of permeable material and some sections of impermeable materials. Figures 4(b), 4(c), and 4(d) illustrate flow joints **51, 53, 50** created by both permeable **55** and impermeable **57** concentric walls and further compartmentalization of the flow joints by adding more walls **59**.

The number of compartments along the circumference depends on borehole size and the type of permeable media. Fewer compartments would enable larger compartment size and result in fewer redundant flow paths if sand infiltrates the first or outermost compartment **51**. The outermost compartment may be partially or entirely defined by a sand screen. An excessive number of compartments would

decrease the compartment size, increase frictional pressure losses, and reduce well productivity. Depending on media type, the second flow joint **53** may be designed to be smaller or larger than compartment **51**. The impermeable walls (solid boundaries along compartments **51** and **53**) could reduce erosion impact from fluid and sands to the permeable media between the outer **51** and inner 53 flow joints, respectively. The multiple compartments in Figure 4(a) could also be unevenly divided or assembled eccentrically in the wellbore.

As shown in Figure 4(a), preferably at least one impermeable and permeable section of the flow joints are adjacent. More preferably, at any cross-section location of the Mazeflo at least one wall of the flow joint should be impermeable. Therefore, there is in this preferred embodiment, at least one flow joint that is impermeable is adjacent to at least one flow joint that is permeable at any cross-section location of the Mazeflo apparatus. This preferred embodiment is illustrated in Figures 4(b), 4(c) and 4(d) whereby there are at any given cross-section location, at least one wall that is impermeable and at least one wall that is permeable.

Additional flow joints may be added as necessary for possible use in gravel packing operations. Figure 5(a) is an example of the Mazeflo completion System and Figures 5(b), 5(c), and 5(d) are cross-sectional views of Figure 5(a) at the designated location of Figure 5(a) wherein like elements are assigned the same reference numbers as in Figures 4(a), 4(b), 4(c), and 4(d). These figures illustrate an additional flow joint utilizing shunt tubes and nozzle ports. Shunt tubes **61** could be placed longitudinally along selected compartments to enhance gravel packing (as disclosed in U.S. Patent Nos. 4,945,991, 5,082,052, and 5,113,935). Shunt tubes **61** are extended beyond compartment boundary **51** into the wellbore annulus **68**. Selected shunt tubes **61** could utilize rupture disks (not shown) and nozzle ports **63** to allow gravel slurry diversion into the annulus **68**. The Mazeflo completion system is suitable for use in both conventional and alternate path gravel packing operations.

<u>EXAMPLE</u>

Figure 6(a) illustrates a side view of the Mazeflo completion system concept of fluid flow redirection during a sand screen failure. The large basepipe is identified as the first or primary joint **13** and the smaller adjacent basepipe is identified as the second or secondary flow joint **15**. In Figure 6(a) there are two sand screens **45** with the sand screens represented in the illustration as dotted lines. The sand screens separate the primary **13** and secondary flow joints **15** from the annulus and also separates the annulus into two annuli. One annulus is between the secondary flow joint **15** and the outer well screen **45**, while the other annulus is between the outer well screen **45** and the formation sand **27**. In this example, the two annuli would be utilized as the third **47** and fourth **49** flow joints.

The embodiment illustrated in Figure 6(a) employs two selectively perforated, adjacent basepipes. The basepipes are impermeable with selected perforation **41** to create regions of permeable surfaces. Each basepipe may be fitted with some type of commercially available sand screen. An additional wall (may or may not be permeable) or baffle **43** may be placed within the larger pipe to redirect flow into distinct flow regions, as shown in Figure 6(a). The spacing of the perforations **41** in each basepipe will determine the relative amounts of fluids that will flow into and between the three compartments. Additional baffles may be placed at various axial locations to redirect flow into different compartments.

For a single joint of pipe (for example, 9 to 12 meters (30 or 40 feet) in length) defining a first flow joint with both permeable and impermeable media, an outer sand screen defining a second flow joint, and a wellbore annulus utilized as a third flow joint, the completion maze will consist of five distinct flow scenarios as discussed above. Persons skilled in the art can configure the pipes wherein conventional tubular connections can be used to join consecutive joints of pipe.

Figure 6(b) is an end view of an eccentric Mazeflo completion system with flow joints created by the sand screens **45** and the wall **43**. The flow joints defined by the sand screens **45** and wall **43** are designated first flow joint **13**, second flow joint **15**, and third flow joint **47** as shown in Figure 6(b).

The areas of impermeable compartments allow fluid flow to bypass areas that are plugged into non-plugged compartments. This commingling permits flow out of a compartment that is plugged into a compartment that is non-plugged. Persons skilled in the art based on the disclosure herein can arrange the compartments to provide adequate commingling to permit efficient flow around any compartments that may be plugged.

Figure 6(b) further illustrates sand screen failure. The solid arrow **17** indicates possible flowpaths and the dotted arrows **48** indicate blocked flowpaths. When the sand screen fails allowing infiltration of sand **42**, one or more compartments could be plugged. However, fluid would continue to flow into the other compartments **47** that are not plugged, and that are protected from the sand infiltration by the additional wall **43**. Therefore, fluid production would continue despite the failure of the sand screen.

The concept of Mazeflo completion was demonstrated in a laboratory wellbore flow model. The flow model had a 25 centimeter (10-inch) OD, 7.6 meter (25-foot) Lucite pipe to simulate an open hole or casing. The demonstrative apparatus, was positioned inside the Lucite pipe and includes a series of three screen sections. The three screen sections consisted of an eroded Mazeflo screen, an intact Mazeflo screen section, and an eroded conventional screen. Each screen was 15 centimeters (6 inches) in diameter and 1.8 meters (6-feet) long. The Mazeflo apparatus included a 91 centimeter (3-foot) long slotted liner and a 91 centimeter (3-foot) long blankpipe as the primary (outer) flow joint. The 7.5 centimeter (3-inch) OD, secondary (inner) Mazeflo joint contained a 1.2 meter (4-foot) long blankpipe and a 61 centimeter (2-foot) long wire-wrapped screen. The primary and secondary flow joints in the tested Mazeflo apparatus were concentric. During the test, water containing gravel sand was pumped into the annulus between the screen assembly (completion system) and the Lucite pipe (open hole or casing).

The slurry (water and sand) first flowed through the annulus and into the eroded Mazeflo screen. The sand entering the eroded Mazeflo screen was retained and packed on the inner (secondary) flow joint. The growing sand pack between the primary (outer) and secondary (inner) flow joints increased the flow resistance and

slowed down the sand entering the eroded Mazeflo screen. As the sand entering the eroded Mazeflo screen was diminishing, the slurry (water and sand) was diverted further downstream to the adjacent intact Mazeflo screen. The gravel sand was packed in the annulus between the intact Mazeflo screen and the Lucite pipe. Since this Mazeflo screen was intact, the sand was retained by the primary (outer) flow joint. As the intact Mazeflo screen section was externally packed, the slurry was diverted to the next eroded conventional screen. The sand flowed around and into the eroded conventional screen. Since the conventional screen was not equipped with any secondary or redundant flow joints, the sand continuously entered the eroded screen and could not be controlled.

The experiment illustrated the Mazeflo concept during the gravel packing portion of well completion operations. If part of the sand screen media is damaged during screen installation or eroded during gravel packing operations, a Mazeflo screen is able to retain gravel by a secondary (redundant) flow joint and enable continuation of normal gravel packing operations. However, a conventional screen could not control gravel loss and potentially cause an incomplete gravel pack. The incomplete gravel pack with a conventional screen later causes formation sand production during well production. Excessive sand production reduces well productivity, damages downhole equipment, and creates a safety hazard on the surface.

This experiment also illustrated the Mazeflo concept during well production in gravel packed completion or stand-alone completion. If part of the screen media is damaged or eroded during well production, a Mazeflo screen can retain gravel or natural sand pack (formation sand) in a secondary (redundant) flow joint, maintain the annular gravel pack or natural sand pack integrity, divert flow to other intact screens, and continue sand-free production. In contrast, a damaged conventional screen will cause a continuous loss of gravel pack sand or natural sand pack followed by continuous formation sand production.